Upgraded Worldwide Ocean Optics Database

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LONG-TERM GOALS

The long-term objective is to provide a comprehensive worldwide optics database that includes data on a broad range of important optical properties, including diffuse attenuation, beam attenuation, and scattering. Data from ONR-funded bio-optical cruises are given priority for loading into the database, but data from other scientific programs (NASA, NODC, NSF) and from other countries will also be routinely added to the Worldwide Ocean Optics Database (WOOD)[1]. The database shall be easy to use, Internet accessible, and frequently updated with data from recent at-sea measurements. The database shall be capable of supporting a wide range of applications, such as environmental assessments, sea test planning, and Navy applications. The database shall include derived optical parameters so that if measured data are not available, the user can obtain values computed from empirical algorithms (e.g., beam attenuation estimated from diffuse attenuation and backscatter data). Uncertainty estimates will also be provided for the computed results.

OBJECTIVES

A main analysis objective has been to determine whether one can use Radiative transfer theory to accurately generate "Derived Parameters." Another objective is to provide data and algorithms having direct relevance to US Navy applications and needs. The US Navy has a special interest in locations such as the East China Sea, Yellow Sea, Gulf of Oman, and the Persian Gulf. Therefore, we will give special attention to testing the algorithms/software using data from such locations. Attention will also be given to testing the methodology within nepheloid layers (sediment-laden bottom waters) because of the US Navy's plans to use optical sensors to detect bottom mines. An on-going objective is to acquire and add new optics data to WOOD, and therefore a related objective is to develop more automated procedures for ingesting new datasets, especially from high-density measurement systems like a glider or SeaSoar system[2]. Finally, assuring high data quality is a major objective, so substantial effort will be given to cleansing raw data from noise, calibration shifts, and other data artifacts.

APPROACH

With regard to the use of Radiative transfer theory to generate derived parameters, we are using multi-wavelength AC-9 and backscattering data to test software such as Kiefer's Hydro-Optical Analysis System (HOPAS)[3]. Essentially one uses a version of HydroLight to "invert" easily measured optical data [such as Apparent Optical Properties (AOPs), irradiance, and radiance], to obtain estimates of Inherent Optical Properties (IOPs). Data from a variety of seasons and locations are being tested in

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order to determine seasonal and geographic dependencies. Our focus is on the empirical relationships among the IOPs known as absorption (**a**), scattering (**b**), and total beam attenuation (**c**), and on the relationship of the various IOPs to the diffuse attenuation coefficient (K). The accuracy of each algorithm will be assessed in terms of absolute errors, such as the root-mean-square difference between measured and calculated values, and in relative terms such as the median absolute *percent* error. The absolute error is used to treat high or low values equally. The relative (percentage) error is used to account for the great variability in attenuation coefficient values as a function of depth.

In performing this algorithm work, we are presently working with Eric Rehm, a graduate student at the University of Washington, to process Sea of Japan data provided by Dr. Greg Mitchell (Scripps). (Those data were acquired as part of a major ONR field program conducted there in March/April 2001.) If that work is successful, then we plan to use high quality military survey data from the Middle East and the Yellow Sea to further test the methodology.

WORK COMPLETED

The main thrusts of our work this past year involved 1) preparing/loading new bio-optical data into WOOD, 2) testing and documenting data thinning algorithms to be applied to over-sampled data, 3) adding software to display statistical summaries of data, 4) adding software to display optical data computed from satellite imagery, and 5) establishing collaborations to investigate automated software that uses Radiative transfer theory to compute derived optical properties. We also replaced the WOOD server with a new, faster PC and upgraded to SQL Server 2005. More detailed descriptions of these accomplishments are included in the following paragraphs.

New Data Added to WOOD: With respect to the preparation and loading of new datasets, Table 1 summarizes what has been accomplished since September 2006. In addition, the following large collections of data are being processed: the Rutgers "RU16" set of 3,226 bio-optical profiles, Dave Siegel's "Plumes and Blooms" data archive[4], and the NASA SeaBASS data acquired since January 2000 (SeaBASS data prior to Jan 2000 are already loaded into WOOD). Figure 1 is an example of the world-wide locations of the new NODC CTD-related data added to WOOD, and Figure 2 is a zoomed in map for the same data showing Arabian Sea c660 nm data locations and the actual profiles.

Table 1. Datasets Loaded into WOOD During GFY 07 (as of 30 August 2007)

Data Description	***Example Number & Types of Profiles***
Mediterranean Sea Atlas 2002[5]	> 3,000 profiles of c660, CHL*a*, nutrients, salinity, & temperature
WHOI Arabian Sea SeaSoar data sets (four cruises)[6]	> 5,000 profiles of CHL*a*, relative turbidity & relative fluorescence, dissolved oxygen, salinity, & temperature data
NODC World Ocean Dataset 2005 CTD data	> 30,000 Secchi depths and profiles of relative turbidity & relative fluorescence, salinity, & temperature data
NODC World Ocean Dataset 2005 CTD data	> 400,000 profiles of CHL*a*, nutrients (O2, NO3, SiO4, PO4), temperature, and salinity
Rutgers "RU6" NW Atlantic glider dataset	2,290 profiles of CDOM, bb470, bb532, bb660, and CTD profiles of temperature and salinity

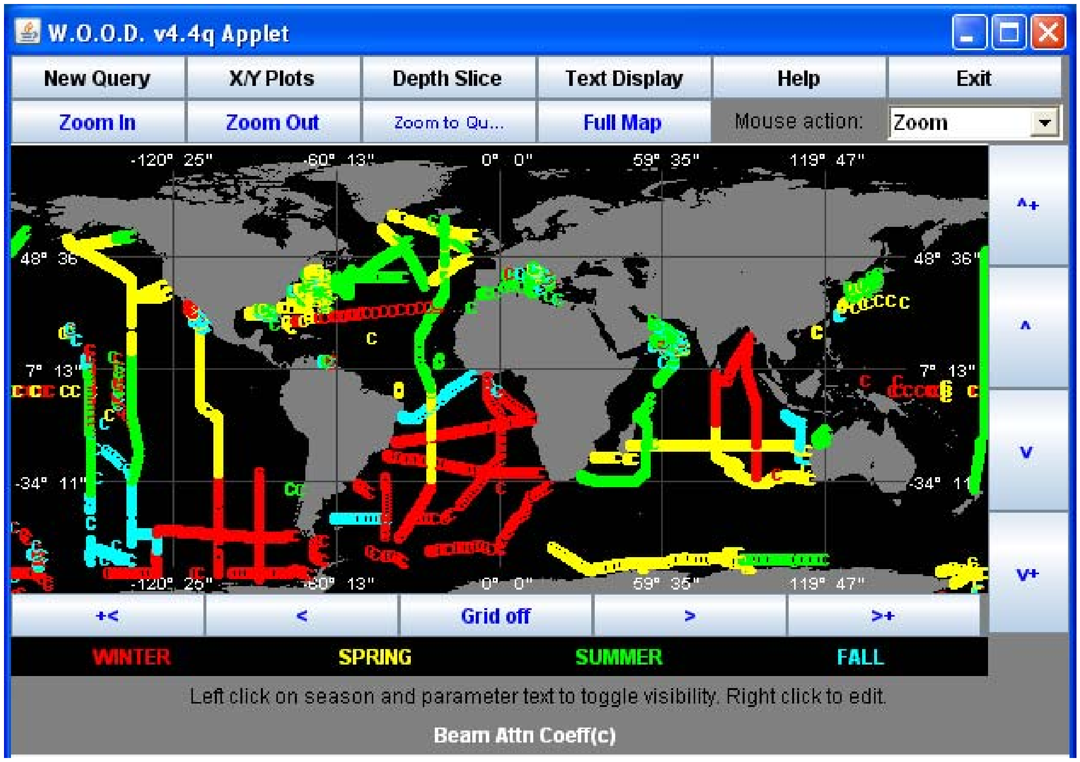

Figure 1. NODC Beam Attenuation Coefficient (c660 nm) Data Added to WOOD in July 2007 [Over 5000 profiles spanning all four seasons and all the world's major oceans.]

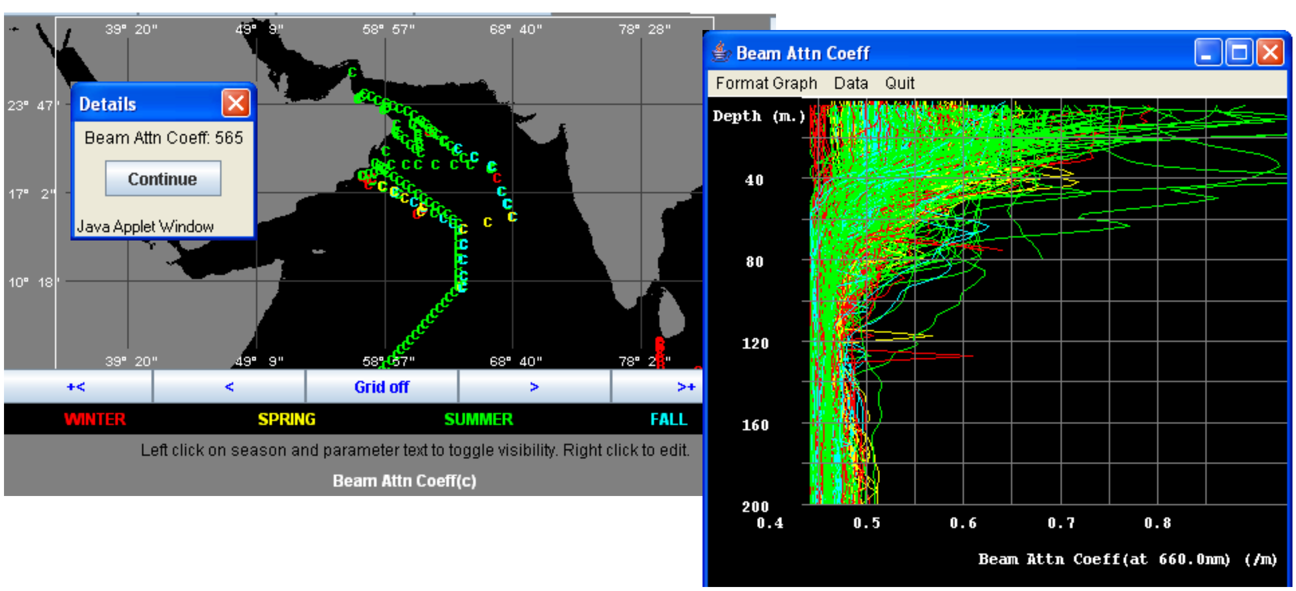

Figure 2. NODC Beam Attenuation Coefficient (c660 nm) in Arabian Sea [Over 500 profiles showing values as high as 1.0/m near the surface but values fall to < 0.5 /m deeper than 100 m.]

Data Thinning Software: JHU/APL data thinning software was applied to all four of the WHOI SeaSoar cruise datasets and also to the Rutgers "RU6" glider dataset. A formal report that documents the algorithms and the software was completed. That report will be used as a basis for a formal journal article to be submitted in 2008.

New Software Added to WOOD: A major new feature was developed and added to the graphical user interface (GUI): the ability to compute and display percentiles on a profile display. Figure 3 shows an example of the 10 %, 50 % (median), and 90 % c532 nm profiles generated by selecting the new "STATS" button on the main GUI window. This feature is especially useful for situations like the one in Figure 2 where there are so many profiles that one cannot discern the overall characteristics of the individual profiles. A similar feature has been added to the mapping GUI for horizontal data slices.

Figure 3. Statistics Plot (10%, 50%, and 90%) of c660 in the Gulf of Mexico. [Values vary from about 0.45 /m to 0.65 /m with the most variability occurring in the upper 200 m and again in the deepest 50 m of the profiles, which reach depths as great as 1000 m.]

While processing/adding Rutgers glider AUV data to the database, JHU/APL also developed software that automatically converts their data format into one that is compatible with the WOOD quality screening and data loading software. In addition, Kevin Barrett, one of the project's three summer students, wrote several valuable Matlab programs that are routinely used to screen and edit raw data: a GUI that maps the locations of specific (mouse-selected) profiles on a map, a function that compares

adjacent profiles and automatically extracts those having salient changes relative to one another, and a function that compares profiles of differing parameters (e.g. a412 vs. a440) and automatically extracts those having salient changes relative to the other parameter. Cyndi Wu, this year's JHUAPL High School mentor student, developed the software that reads and processes the hundreds of thousands of profiles found in the NODC World Ocean Dataset 2005 files.

The most significant software development effort involved writing Java code to ingest and display the NASA MODIS satellite imagery files of K490. This code, which is based on an earlier Matlab program, also allows the user to perform wavelength conversions (using the Austin-Petzold empirical algorithms[7]) to provide K at other wavelengths between 412 and 660 nm. Figure 4 is an example of a K490 product for the Northwestern Pacific Ocean in the month of June.

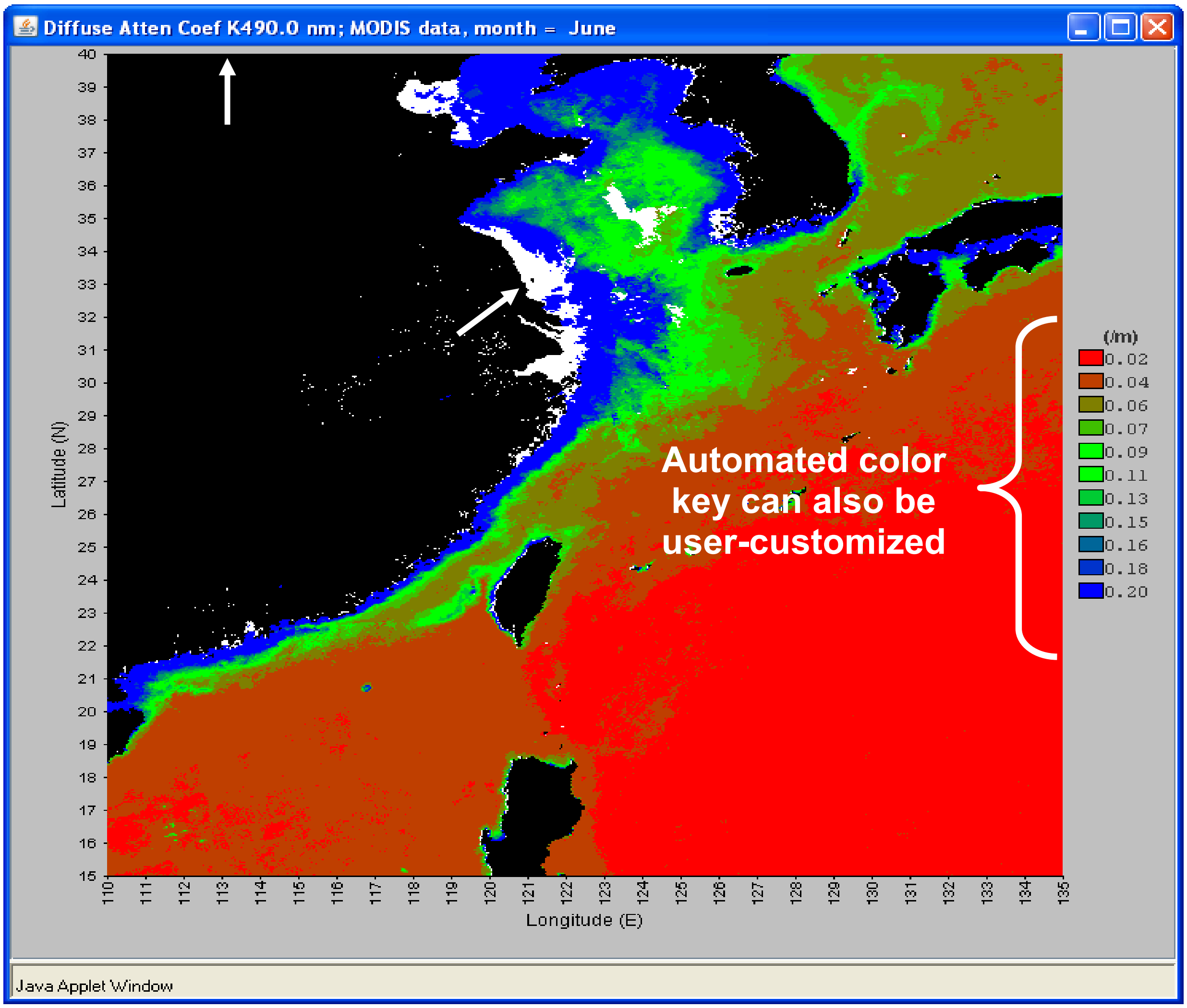

Figure 4. Example of new WOOD (Java) Satellite Imagery Display. [Deep ocean regions have K490 < 0.02 /m while waters close to the coast can have K490 values > 0.2 /m. Land is in black and persistently cloudy regions are in white.]

Empirical Algorithms: A formal journal paper was submitted and published that describes the empirical algorithms used to estimate optical parameters from other measurements. In addition, sample data from the Sea of Japan have been sent to Eric Rehm (University of Washington) to test the use of HOPAS and his related, newer Radiative-transfer-based software for estimating optical data from multi-wavelength absorption, beam attenuation, and optical scattering depth profiles.

RESULTS

Many thousands of investigators from around the world have made use of the WOOD. The rate of usage has also dramatically increased from about 1200 unique IP addresses per year in 2001 to about 11,000 in 2004 and to about 20,000 since 2005. WOOD is routinely accessed by a wide variety of schools, colleges, universities, research institutes, and various DoD/US Government/State-Local Government agencies. Table 2 (shown on the next page) is an example of DoD/US Government-related "hits."

As specific examples of US Navy use, the ONR Littoral Warfare Advanced Development (LWAD) Program used WOOD data extensively in planning for the LWAD 03-4 Sea Test in the East China Sea. In addition, the Environmental Support Systems Project within the SSBN Security Program uses WOOD on a variety of classified tasks. WOOD has also been used to directly support our ONR sponsor, Dr. Steve Ackleson. For example, in 2005 he requested an analysis of the ~ 30,000 K profiles in WOOD that exist on the continental shelf in order to determine the fraction of the world's continental shelves that are sufficiently clear to allow a bottom-mounted sensor to measure downwelling radiance.

IMPACT/APPLICATIONS

By requiring all projects funded by ONR's Ocean Optics Program to submit their data to the WOOD, ONR is ensuring that these valuable data continue to be available for current and future investigators. Furthermore, it is estimated that the availability of a single location, uniform-format optics database has saved the US Navy many thousands of dollars in test planning and other naval applications. By providing the Navy and the research community with this resource, both types of users benefit from improved knowledge of the optical properties of the ocean. Access to historical optics data can also be useful for assessing newly acquired data. One can compare the two to see if the new results are atypical, and if so, one might go on to determine the cause (e.g. unusual forcing conditions, influx of a different water mass, or perhaps even an instrument calibration problem).

TRANSITIONS

In June 2006 CAPT Kiser (CNMOC) issued a directive for NAVOCEANO to establish an agreement with JHU/APL for transition of a classified version of WOOD to NAVOCEANO. JHU/APL delivered a draft Technical Transfer Agreement (TTA) to NAVOCEANO in October 2006. As of September 2007, NAVOCEANO has not made the necessary steps to effect this transfer. Meanwhile the SOCA project has expressed interest in acquiring at least part of the WOOD system as part of their effort to develop a classified database similar to the Submarine Operational and Research Database (SOARED; see http://wood.jhuapl.edu/soared/welcome.htm.) that is a partial clone of the WOOD database.

Table 2. Partial List of DoD/US Government -related "hits" to WOOD from July 2005 to July 2006

- Air Force Logistics Command
- Air Force Materiel Command
- Air Force Systems Command
- Air National Guard
- Andersen Air Force Base
- Center for Naval Analyses
- Defense Advanced Research Projects Agency
- Defense Technical Information Cntr
- Department of Veterans Affairs
- DoD Network Information Center
- Dover Air Force Base
- Federal Aviation Administration
- Headquarters, U.S. Army Recruiting Cmd
- HQ US Army Medical R& D Command
- Info. Systems, U.S. House of Representatives
- Institute for Defense Analyses
- Keesler Air Force Base
- Los Alamos National Laboratory
- National Aeronautics and Space Admin.
- National Center for Atmospheric Research
- National Institutes of Health
- National Oceanic and Atmospheric Admin.
- National Wetlands Research Center, USGS
- Naval Cmd Control & Ocean Surveil. Center
- Naval Postgraduate School
- Naval Research Laboratory (Stennis)
- National Center for Supercomputing
- National Climatic Data Center
- National Computer Security Center
- National Inst. of Standards and Technology
- National Institutes of Health
- National Oceanic and Atmospheric Admin.
- National Park Service
- National Renewable Energy Laboratory
- National Wetlands Research Center, USGS
- Naval Postgraduate School
- Naval Research Laboratory
- Naval Surface Warfare Center
- Naval Undersea Warfare Center
- Naval Undersea Warfare Cntr., Keyport
- Naval Undersea Warfare Engineering Stn
- Oak Ridge National Laboratory
- Office of the Chief of Naval Research
- Pearl Harbor Naval Shipyard
- Randolph Air Force Base
- Sandia National Laboratories
- U.S. CENTRAL COMMAND
- U.S. Dept. of Agriculture – ARS
- U.S. Dept. of Commerce – ITA
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Army Corps of Engineers
- U.S. Army Space and Strategic Defense
- U.S. Department of Energy
- U.S. Department of State
- U.S. Department of Transportation
- U.S. Dept. of Commerce NOAA-NMFS
- U.S. Dept. of Health and Human Services
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- United States Naval Academy
- Wright-Patterson Air Force Base

RELATED PROJECTS

The project's Principal Investigator, Jeff Smart, is a Project Manager and Lead Scientist on several classified projects that regularly use WOOD data to plan US Navy field tests and to conduct vulnerability studies. Mr. Smart is a also a member of the ONR Littoral Warfare Advanced Development (LWAD) project that conducts numerous at-sea tests, including tests involving optics in overseas areas of special interest to the US Navy. Via the LWAD project, the WOOD project has obtained important optical data in the East China Sea and the Yellow Sea. WOOD also provides LWAD with optics data for test planning purposes. The Applied Physics Laboratory works closely

with the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS) community in order to ensure that their bio-optical data are regularly added to the WOOD. In order to foster this relationship, US Navy permission was obtained to provide unclassified LWAD optics data (collected by JHU/APL scientists) to SeaBASS.

PUBLICATIONS

Smart, J.H., "Empirical Algorithms for Ocean Optics Parameters," *Optics Express,* Vol 15, Issue 12, pp 7152-7164 (Jun 2007)

Smart, J.H., "Predicting Optical Clarity in the Littorals," *Journal of Underwater Acoustics* (July 2007)

Smart, J.H., "The World-wide Ocean Optics Database (WOOD) – Ten Years Later," [paper presented at the *Ocean Optics XVII* conference, Montreal, Canada, October 2006]

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